THE ICE-FLOOD HYPOTHESIS OF THE NEW ZEALAND SOUND BASINS

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INTRODUCTION

The author feels confident that the glacial explanation of the striking geographic forms in the southwestern Alps of New Zealand finds readier acceptance among those students who, until such time as they themselves have conducted careful and detailed physiographic examinations, have not so much as seen a region of former or present intense glaciation, than with those who have spent their lives amid such ice-modified surroundings. Only to such workers does the whole series of novel perceptions presented during a first glimpse at a formerly strongly glaciated region come with the startling force of a revelation. The foregoing is applicable to the case of the author, and because of it he feels warranted in presenting this glacial explanation for certain New Zealand forms. For several years prior to visiting Alpine New Zealand in the summers of 1901 and 1902, he had made numerous topographical observations in Australian New England, Monaro, The Darling Downs, northern Queensland, and Fiji. Between the latitudes embracing these localities, viz., 15° and 37° S., thousands of tributary water-courses had been inspected. All were observed to join the main river channels with non-conflicting, or but triflingly conflicting, grades. The magnificent plateaus of eastern Australia still, in great measure—when composed of felsites and acid granites—retain their individuality as to their central portions, and here, naturally, as they are traced headward, the rivers are observed to leave the wide and well-matured valleys of the uplands in gigantic waterfalls for rapidly trenching canyons. But even at this *initial* stage of canyon growth, with one or two exceptions, easily explicable by local rock variations, etc., the legions of side gulches, although insignificant in length, come in "at grade." Thence, follow-

ing the canyons in their intricate windings to the points where stream corrasion has destroyed the individuality of the plateau, one finds a ceaseless repetition of contracted waterways, tortuous channels, and myriads of overlapping spurs. Above all, the absence of lakes and the wonderful constancy of the "graded" water-courses were marked features.

The first sight of the New Zealand fiords and the Alpine lakes was marvelously contrasted to Australian scenic types, where glaciation had had no part in determining the valley contours. Here (in New Zealand) were great rock basins, broad flat-bottomed valleys, with bordering walls rectilinearly disposed as to their bases, and of even dip, but of such steepness as to be inaccessible to any but daring climbers; a marked absence of spurs; and an arrangement of such valley buttresses that they appeared shriveled up to the canyon walls, their terminations ending in tremendous precipices, the bases of the same being usually in alignment. Here also one saw *lines of sentinelling domes* rising thousands of feet into the air—a prevalence of rock monuments suggestive of sitting lions—and numerous deep and fairly broad-bottomed canyons connecting with the sounds and larger valleys over gigantic walls flush with the main rectilinear ramparts. These remarkable side valleys, seen from below, appeared to spring direct through U-shaped notches in the vertical walls. In the crystalline schists these walls were at times almost monotonously majestic in their steepness and evenness of slope, as in Milford, while in the softer schists of Wakatipu the valleys were broader, the slopes less, and the "hanging valleys" a minor feature. Then again there were the gigantic moraines of the lakes; and, perhaps most striking of all, the wondrous *cirques* or amphitheaters, thousands of feet in height, which, in the denser rocks, almost prohibit the scaling of divides.

No one form just enumerated found a response in the stream-developed contours of the eastern Australian cordillera. The fact was, moreover, well established that this fiord and lake land had been demonstrated, by many workers, to have been one of former intense glaciation, and as such an attempt was made by the writer to furnish a glacial solution to the problem. While still puzzling over the "hanging valleys," Professor W. M. Davis' note on glacial

forms in Norway, Switzerland, and England came under my notice, and, with minor modifications only (as will be seen in this note), appeared competent to explain the New Zealand forms. Later, Dr. G. K. Gilbert and Willard D. Johnson, of the United State Geological Survey, kindly forwarded copies to me of their notes on *cirques* and allied phenomena in northwestern America.

After the publication of the Dunedin note, the importance of the ice-flood hypothesis as explaining the *peculiar* "sound" shapes and the *present inactivity* of glaciers forced itself upon me. The present note is the result.

I desire here to mention the great help derived from a perusal of some of the glacial reports written by Professors T. C. Chamberlin, R. D. Salisbury, W. M. Davis, T. W. E. David, and James Geikie, Dr. G. K. Gilbert, Professor J. W. Gregory, Sir James Hector, Professor F. W. Hutton, Von Haast, Willard D. Johnson, Dr. Lendenfeld, F. C. Matthes, and Professor I. C. Russell. To a great deal of the literature no access has been obtainable.[1]

THESIS

The Great Ice Age marked a flood in glacial action, while the present warm conditions obtaining in these areas of former intense ice-action marks a glacial drought.

The sounds, lakes, and canyons of southwestern New Zealand were determined, for the greater part, by preglacial streams whose channels had attained to the graded stage.

During the height of the ice-flood the glaciers gouged out deep basins much below the baselevel at points near the convergence of profound canyons. Here also they ripped off spurs, aligned and even undermined the walls, thus producing double canyon-cliff slopes.

At other points, such as "broads" and other quiet spots in the preglacial canyons, the ice-scouring was not pronounced. Also at all points away from the central channels aggradation and minor scouring would be noticeable.

Recession of the ice-flood brought about obliteration of former deep groovings in the rock basins and canyon walls, aggradation was almost suspended in the later drought stages, and overriding of old

[1] Since writing the above, I have received a glacial note supplied to the *Journa of Geology* for 1905, by Professor Albrecht Penck.

moraines and general ice-stagnation resulted, inasmuch as the old flood-scoured channels were now too broad and of too slight a grade to admit of further corrasion by the present insignificant representatives of the former glaciers.

CHARACTERISTIC TOPOGRAPHIC FEATURES OF SOUTH-WESTERN NEW ZEALAND

1. *Plateau remnants.*—Around Milford Sound, Lake Te Anan, and Lake Wakatipu there exist numerous sub-horizontal masses

FIG. 1.—Clinton Gorge, showing dismantled plateau, spurless chasm, and wide canyon floor. In the foreground to the right lies a large *cirque*.

(Fig. 1), and long ridges attaining heights of from 5,000 to 6,000 feet. Above these again rise peaks and masses to heights of 10,000 feet. Farther south sub-horizontal masses of much less elevation are encountered (Fig. 2).

These are apparently survivals of a flexed surface, the upland itself representing the advanced maturity of subaerial erosion (in pre-Tertiary times), when the land was at a much lower elevation.

2. *Hanging valleys.*—These remarkable topographical features are most pronounced in the dense crystallines of Milford Sound, while in the softer Paleozoic schists of Wakatipu they are reduced almost to insignificance. They possess fairly evenly graded channel slopes almost to their point of discharge into the main stream. This they join either in cascade form or as sheer waterfalls as much as 2,000 feet in height. In the crystallines the wall which holds the notching hanging valley is generally possessed of a rectilinear base, the preci-

FIG. 2.—Preservation Inlet. Dismantled plateau at much lower level than that in Fig. 1. Also wide valleys.

pice which borders the sounds or canyons at these points being continuous across the inter-hanging valley mouths. This gives a most remarkable appearance as contrasted with typically stream-developed areas (Fig. 3). Magnificent examples of these hanging valleys are the Sinbad Valley (Fig. 4), the Stirling Falls (Fig. 3), and Bowen Falls (Fig. 5).

3. *Rectilinear cliff bases.*—These forms are found in the Hollyford and Clinton canyons, but are even more pronounced in Milford Sound (Fig. 6), and the side valleys of the Cleddau, Arthur, and

Harrison Cove streams. The mountains composing the sides of the valleys of the Wakatipu and Milford Sound types, may be notched and broken by deep ravines reaching down to the water's edge; they may appear even as isolated *bee-hive* and *sitting-lion* shapes; yet their immense bases almost uniformly preserve a wonderful alignment.

4. *Truncation of spurs.*—All stages in apparent truncation of

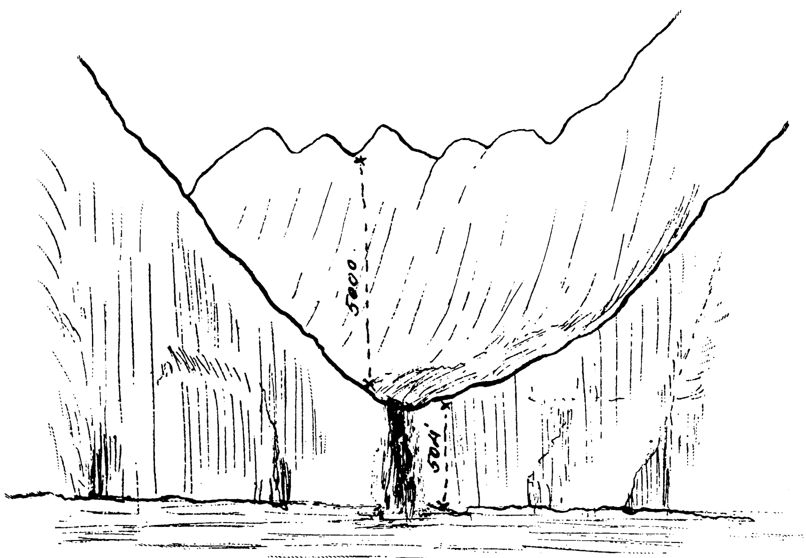

FIG. 3.—Sketch of Sterling Falls, 504 feet high. (From a photo.) Note the alignment of the canyon walls, and the steepness and evenness of the hanging valley walls.

spurs may be found in the sounds and side canyons. The idea suggested from a study of these forms is that of a former series of overlapping spurs which have been subjected to some mighty force, whose maximum strength had been exerted along the lower and central valley channels, causing the planing off of spur ends in some cases, and utter shriveling up of spurs against the canyon walls in others. The more complete truncation of spurs would, of course, result in more perfect alignment of cliff bases.

Examples of these progressive stages in apparent spur truncation are shown by Figs. 7, 8, 9, and 6.

Sitting-lion forms and great bee-hives or domes are also the expression of this apparent mutilation of once long rambling spurs.

5. *Double cliff slopes.*—A feature characteristic of the dense crystallines of Milford and its side canyons especially. Along the bordering walls of these canyons the lower portion is often observed to be absolutely perpendicular for as much as from 1,000 to 2,500 feet. Above these rise the characteristically even, but very steep,

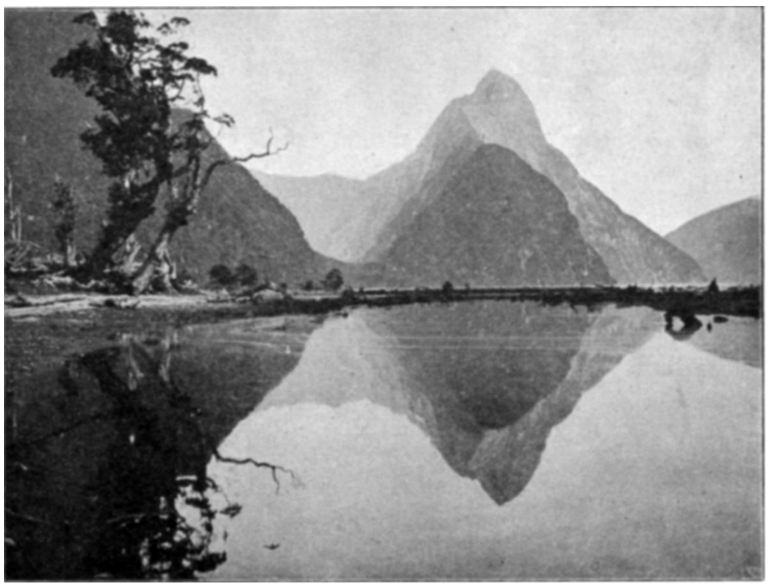

FIG. 4.—Mitre Peak (5,600 feet) and Sinbad Valley. Milford Sound. Note the inaccessible walls of the hanging valley (Sinbad).

rock slopes (Figs. 11 and 12), for other 3,000 feet. Usually the sides rise for some 4,000 or 5,000 feet in this steep fashion (slope about 50° to 60°), but in many places these tremendous lower perpendicular slopes come in. Just below the points of convergence of two steep and deep canyons the feature is much emphasized. Figs. 9, 10, 11, and 12 illustrate the point.

CONTOURS OF SOUNDS AND LAKES

Associated with these double slopes of Milford are found deep rock basins having fairly flat bottoms and almost perpendicular

sides (Fig. 12). These features are also accentuated just below points of deep canyon convergence. The central portions of these rock basins are the deepest, and sounding lines 1,700 feet in length have been employed without reaching bottom.

Generally the sound entrances are *much* shallower and narrower than portions much higher up-stream.

PREGLACIAL HISTORY

The plateau which survives now as ridges and mesas from Lake Wakatipu to Preservation Inlet probably marks the old-age stage of erosion of a surface originating in the Mesozoic folding[1] of southern New Zealand. Differential elevation then ensued, which carried the plainlike surface (developed near sea-level) of the closing cycle of erosion to considerable heights. The early Tertiary sedimentation was probably induced by this deformation. Canyons early became the expression of the cutting action of the streams on the raised area, and during Eocene times a series of anastomosing and graded water-courses were developed in the area. Subsidence ensued, closing the Eocene erosion, the valleys were deeply drowned; and thick masses of Oligocene age were deposited on the Eocene valley floors. This has, it seems to me, been admirably demonstrated by Hutton,[2] in his reply to Von Haast's[3] assertion that the canyons of the New Zealand Alps are due entirely to ice-action; for, according to Hutton, Oligocene limestones occur on the lower slopes of Lake Wakatipu, this same valley having been carved out of the schists by streams in Eocene times on the uplifted plain. Therefore, taking Lake Wakatipu as a type of these lakes and fiords, we are driven to the conclusion that deep valleys had been carved in the hard Paleozoic complex by Eocene streams, and that on subsidence ensuing at the close of that period, the lower valleys were drowned and Oligocene limestones deposited.

Afterward elevation ensued, and the forces of subaerial erosion once more came into play. Now, if stream-erosion here was com-

[1] F. W. Hutton, *The Geology of Otago.*

[2] *The Geology of Otago*, pp. 86–94. This volume is a real treasure-house of general geological knowledge for southwestern New Zealand.

[3] *Geology of Canterbury and Westland*, pp. 177–92.

parable to that obtaining on the neighboring Australian continent, then a whole host of overlapping spurs must have characterized the headward growth of the canyons. One, however, looks for them in vain. The plunging waterfalls one expects to see are absent from

FIG. 5.—The Bowen Falls, 550 feet high. A hanging valley in Milford Sound Note the evenly steep walls of the valley.

their heads, being found perched along the canyon *sides* instead, while enormous and almost inaccessible *cirques* represent the initial stages in canyon growth.

The great glacial epoch has come and gone, and with its passing the resurrected topographic forms are seen to be totally different

from forms which we know to be developed by streams in *non-glaciated* areas.[1]

Here, then, is strongly suggested a glacial origin for these forms. In the succeeding pages an explanation of these geographic features is attempted.

FIG. 6.—The northern wall of Milford Sound. Note the alignment (and double slope) of walls at Stirling Falls; also the "hanging" valley to the extreme left.

THEORETIC CONSIDERATIONS

It is here proposed to explain the peculiar topography of the southwestern New Zealand sounds, lakes, and canyons as the result of great ice-floods working along lines of preglacial drainage, developed to late youth or early maturity in lofty plateaus having rapid fall to baselevel (generally sea-surface), and to show that the present glaciers must necessarily, from analogy with ordinary stream-action, be practically stagnant.

The similarity between ice- and stream-action need not be at all

[1] Similarly for the like features of the once strongly glaciated fiord regions of Alaska, Norway, and Patagonia.

strained in this connection. It is only necessary to assume that ice acts somewhat as a viscous body; i. e., that its surface should show a gradually curving fall from summit to baselevel. Thus we get increased velocity with increased volume of ice, as with ordinary streams, and the capacity for work exhibited by the more quickly moving mass is not related by a simple ratio to that performed by the more slowly moving one.

FIG. 7.—Wet Jacket Arm. Note the partial truncation of spurs resulting in precipitous facets facing the Sound.

The same idea of wonderfully increased efficiency as regards cutting, transportation, etc., is seen also during the convergence of two ice-masses into a canyon of very little greater width than either of the two feeders.

TOPOGRAPHIC CONDITIONS OBTAINING IN SOUTHWESTERN NEW ZEALAND

1. We have a much dismantled plateau in the area under consideration (Figs. 1, 2, and 7). Great convergence of these plateau remnant valleys to the later canyons is often observable.

as it deals with the origin of present-day surface contours.

2. The channel bottoms of the incising canyons show *gentle* grades almost to the very heads of the valleys; huge rock basins also exist, the floors of which are frequently lower than the valley bottoms, and are at times far below base- or sea-level itself.

3. Convergence of steep canyons is pronounced, and often marked by the association of huge rock basins, straightened and often per-

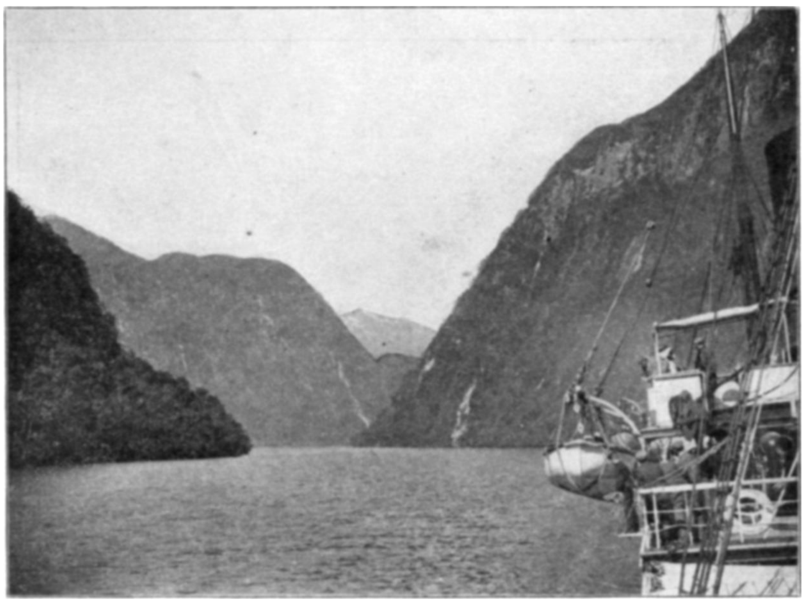

FIG. 8.—Crooked Arm. More advanced stage of spur truncation than in Fig. 7.

pendicular lower canyon walls (Figs. 5, 6, and 9), surmounted by steep, even slopes.

4. An immense precipitation is shown for this area, the average probably exceeding 150 inches per annum.

5. Whatever the nature of the agency which imposed these peculiar topographic features on the landscape, the recency of the same and the character of the rocks acted upon have permitted of no alteration in their general appearance.

The problem under discussion is a physiographic one, inasmuch as it deals with the origin of present-day surface contours.

ACTION OF FLOODS ALONG MATURELY DEVELOPED STREAM CHANNELS

The maturely developed stream channel is composed of reaches of alluvial flats, alternating with graded rocky slopes. These alluvial stretches may be regarded as fleeting baselevels. In periods of ordinary water the stream accomplishes very little cutting or transporting, its energy being absorbed in establishing a perfect adjustment of channel grade, which has been temporarily upset by a freshet

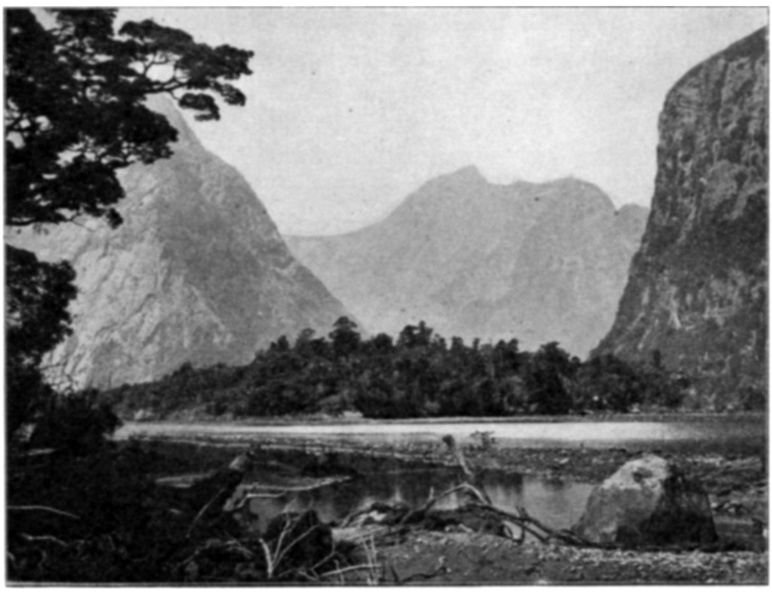

FIG. 9.—The Arthur River at its entrance to Milford Sound. Note the double cliff slope of Sheerdown Hill to the right. See also in this connection Fig. 11.

or flood. Consider now the effect of a great flood on this graded channel. Along certain points of the channel—notably where convergence of streams occurs—deep holes are scooped out below the temporary baselevels. In many cases, along the lower stream courses, basins are formed whose floors lie considerably below their grand baselevel (generally the sea-surface). Every physiographer is aware of such facts. Excavation of banks also keeps pace with this scooping action. Nevertheless, on the other side of the stream aggradation is proceeding hand in hand with this corrasion. The

flood waters which at times surmount the stream banks and spread over the surrounding country are for the most part observed to be stagnant and to form "back-water" masses, in which some aggradation goes on. If some previous channel or natural valley is found by this trespassing mass, a considerable amount of corrosion may occur even at these higher points. This is, of course, in the broads of the stream. In the narrows there is little chance for back water, except in sheltered corners opposite the cutting curve.

FIG. 10.—Lower Milford Sound. Note the immense double slope on the left.

All this is, of course, quite natural. However high the flood, however much it overflows its banks, we expect the maximum strength to occur at or near the central channel portion, while away from the drainage channels we expect aggradation and even stagnation.

With the recession of the mighty flood, we do not expect a continuation of basin excavation below baselevel. On the contrary, we look for aggradation at these points until the normal stream-channel slope has been restored. Nor do we expect the drought-stricken stream to rouse to action the huge loads of flood bowlders littering its channel, and with them to tear away the sides and bottom, even

as in times of heavy water they struck each other and the containing banks wildly until their shrieks could be distinguished above the roar of the escaping waters. On the contrary, we expect the reduced stream to gurgle *among* the flood bowlders, to override the banks of débris, or to become stagnant even in the depressions. Thus the recession of high water is seen to act in the direction of obliterating the marks made by storm waters.

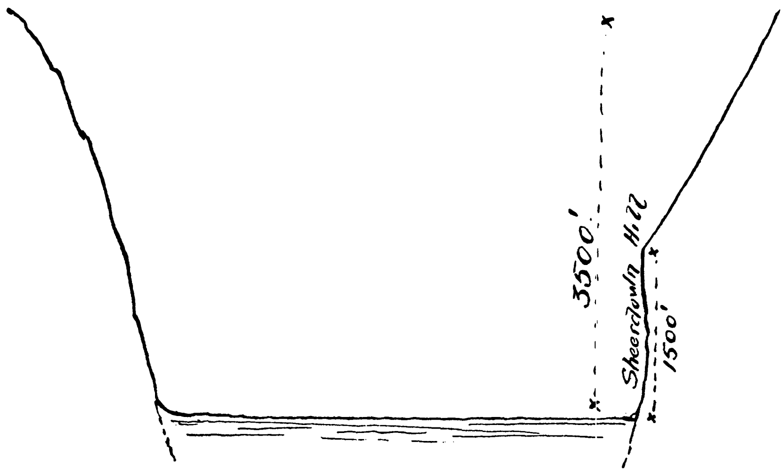

FIG. 11.—Sketch section across the Arthur River mouth. (From a photo.)

Again, in proportion to the advanced degree of stream reduction attained in any region, so are the flood forms just enumerated less and less accentuated in areas of hard, solid structures.

APPLICATION TO ICE-STREAMS

If now the writer has succeeded in stating his case for stream-action clearly, the far-reaching effects of its application to glacial studies must be apparent at once. For it is indisputable that the recent Ice Age marked a glacial flood, while the present insignificant glacial representatives of that momentous period indicate a pronounced ice-drought.

Let us review briefly the probable action of glaciers in these pre-glacial stream-developed canyons of southwestern New Zealand. As a type of a valley developed by stream-action to the stage of late youth or early maturity, the accompanying sketch of Moonan Brook

(Fig. 13) (in New England, New South Wales), may suffice. Here a valley some 3,000 feet deep is seen, many overlapping spurs being noticeable.

We will suppose that convergence of plateau remnants to heads of canyons, as also of these deep valleys into each other, is a common feature.

With the increase in ice-volume, the valley becomes gradually

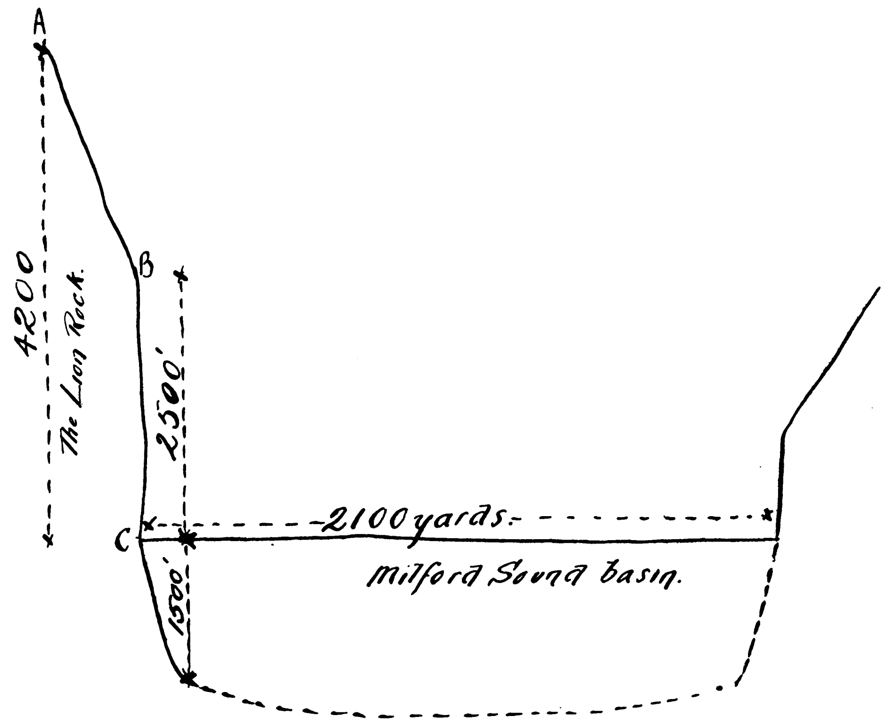

FIG. 12.—Sketch section across Milford Sound. (From a photo.) To the left are seen the effects of the heavy ice-thrusts just below the convergence of Arthur, Cleddau, and Harrison Cove streams. Fifty yards from its cliff, the Sound is 1,500 feet deep.

filled with a glacier. With increased volume or convergence (the confluent ice-surfaces will generally keep at same level) comes added velocity. The directions of flow have been determined for it and its tributaries by the preglacial streams, and the lines of maximum depth and motion will be along the portions vertically above the old stream channels. Even should the glaciers fill the valleys, the higher

they rise above the canyon rims, the stronger the resultant thrusts along the central channel, as in the case of ordinary stream floods. Along the lower spur ends the maximum force will thus be early expended. The upper portions of the spurs will experience great wear and tear, but the amount will be trifling as compared with that felt by the spur portions near the base of the central channel. The rock load, as also bottom friction, will cause reduction of speed along the *lowest* portions of the glaciers, and, as with streams, we

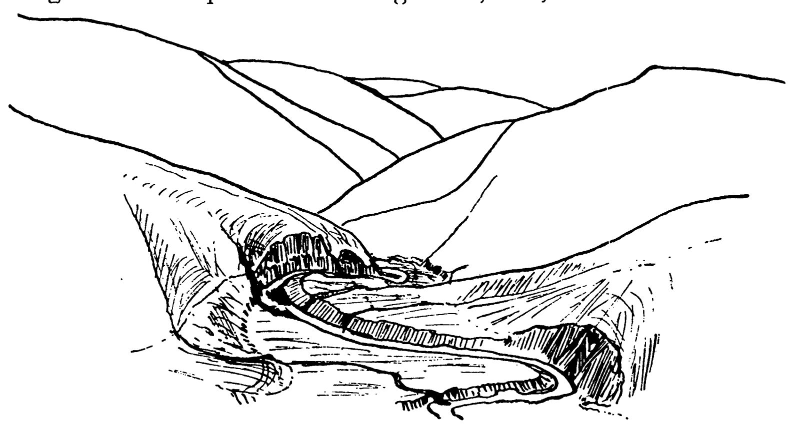

FIG. 13.—Sketch of Moonan Brook (New England, New South Wales). A typical stream-developed valley. Note the overlapping spurs, the spur-cutting and aggradation by floods. Canyon about 3,000 feet deep.

would expect the maximum velocity to occur along the central channel at some point intermediate between the surface and base of the moving ice-mass. Under the tremendous scouring action of the armed glacier, we would then expect the lower spur ends to suffer first. Fig. 7 appears to illustrate this stage of planation. Here the floating spur ends have vanished, and precipitous facets to the sound are presented by the truncated masses.

All this time the glacier is increasing its load, and, as with streams, the strong cutting action may have to be suspended (during local slackness in ice-supply) until the excess of load has been removed. Also as with streams, the degree of spur planation will depend upon their arrangement and development. Small spurs in the direct line of flow will early suffer complete removal, while large ones, favorably situated as regards their preservation (points opposite the cut-

ting curves) will show truncation on certain sides only. Fig. 8 illustrates this well. As the ice gathers strength, it will possibly surmount the great canyon walls, and actually flow over the old, flexed upland. This stage may be considered the period of maximum ice-flooding. After the almost complete truncation of spurs in softer rocks, slopes of moderate batter will be induced in the canyon sides, as they will be too weak to resist the lateral thrusts

FIG. 14.—Sutherland Falls, 1,904 feet high, from a hanging valley which is mature and 2,500 to 3,000 feet deep. Upper Arthur River. Note the majestic wall and notch through which stream comes. Here two deep valleys converge to form Arthur River.

from the swiftly moving glacier. Deep holes will also be plowed in the bottom rocks to great depths below local baselevels. But in the narrower canyons of the dense crystallines, as around Milford Sound, especially where the steep canyons are from 5,000 to 6,000 feet deep, and where marked convergence of valleys occurs, the results will be marvelous. The resultant ice-velocity is much increased as the converging masses are forced into a deep valley only slightly broader than either of its tributaries. The spurs are ripped off, but the resulting massive and aligned walls present great

resistance to the mighty ice-flood. The differential strength of the converging glaciers in their upper and lower parts will be pronounced. Undermining action will set in. The upper portions will be slowly worn back to steep, even slopes, but the cliff bases will experience such tremendous lateral thrusts that perpendicular and even overhanging slopes will be produced at points somewhat lower than halfway down the valley sides. The disposition of the converging valleys will indicate which side of the lower canyon is selected for special attack. In exceptional cases[1] bottom thrusts will also, near these points of canyon convergence, excavate rock basins possibly several thousands of feet in depth below baselevel.

Figs. 6, 9, and 10 illustrate these stages in wall and bottom excavation in the narrow crystallines.

With the *undermining* action by the heavy lateral thrusts of the lower portions of the glacier, the lower ends of many weaker tributary valleys will be shorn off, and their mouths will be left hanging along the aligned cliff bases.

Figs. 5, 6, 11, 12, and 14 illustrate these points well. The diagrams are taken from photos of Milford and the Arthur River. No one, we venture to say, could see lower Milford Sound and fail to see in it a *heavy* ice-flood working along lines of preglacial drainage.

As might have been expected, the northern wall of Milford has been selected for special attack. This is well seen just below the junction of the Arthur and Cleddau canyons, but the point is still further accentuated a little farther down, where the immense glacier of Harrison Cove was picked up. The great corrasion of the eastern wall of Harrison Cove is also noticeable as compared with that of its western one.

Beyond these points come the evidence of minor spur truncation only, the contracted sound entrances, and the shallowing of fiord waters. As we might have expected, the huge rock basins and associated "hanging valleys," double cliff slopes, etc., are seen in places like this where the ice-fall is pronounced. Beyond this plunge to baselevel we should expect comparative stagnation.[2]

[1] The depths attained will be a measure of the thickness of the ice-sheet.

[2] From considerations of lack of gathering ground for ice, the cessation of corrasive power after fall to baselevel, etc.

But even in periods of maximum ice-flood many broads or divergences in the channels (canyons) would form spots where aggradation or partial glacial stagnation would occur. The deep fiord basins, with their associated lower precipices, steep, even upper slopes, aligned cliff bases, and "hanging" valleys, mark points of maximum ice-scour, and oçcur in exactly the positions where we would expect to find them; but there are other spots at which we would expect to have evidence of much less efficiency of ice-corrasion. This is even so. At these points spurs are not observed shriveled up to their containing walls, nor are rock basins found. These points correspond with the smoother waters of a stream-flood. In the canyons themselves these evidences of weakened erosive power may occur only at some *considerable height above the channel bases.*

Again, as the ice-flood in places welled over the canyon sides after the manner of a river overflowing its banks, so we could expect very little comparative scouring to occur at these points. There will be no natural drainage lines to follow at this level, and the ice-overflow will here expend most of its energy in opposing gravity as it rises above the upland irregularities. Aggradation with pronounced stagnation results from this. *Old* drainage lines may, of course, be found, and here, especially on declines,[1] ice-corrasion may be considerable; or the ice-cap may open onto the steep sea-front and set up incipient valley formation here. "Hanging" or even graded valleys may result thus, if the ice-flood be of considerable duration in time.

Consider now the effect of diminishing the ice-supply. Decrease of volume is marked by loss of speed, and this by a *wonderfully* decreased capacity for work. Long before ice-drought conditions shall have set in *active* corrasion will be suspended, and *aggradation* will be the order of the day. For during the period of flood the channel bases have been graded so as to be adjusted[2] to the heavy burdens passing over them. Now an ordinary stream[3] is wholly

[1] The writer would insist on the idea being kept in mind that a glacier should corrade more on a *decline* than on an *incline.*

[2] A stream-flood may occupy several days only, while the glacial period (summation of ice-floods) probably lasted very many thousands of years.

[3] We should say this law applied to viscous substances generally.

or mainly functional in readjusting the grade along which a *mighty flood only* could do effective work. Until such time, aggradation at the majority of points will ensue. Thus it is with our retreating ice-stream. The deeply scored channel, the huge rock basins (between widely separated canyon precipices adorned with "hanging" valleys), marked the grade along which the ice during a maximum flood *only* could accomplish work. The least retreat of the flood would cause cessation of cutting at these points. Although the canyon ice-overflow might be stopped, yet the canyon itself might be full. Nevertheless, cutting work would be ceased along these points of maximum excavation, since pressure and speed have been reduced in the central channels. The only work the glaciers can now accomplish along the rock basins will be the partial, or at times even complete, obliteration of the deep grooves which marked their high-flood attack. Hence we should expect the rock basins to lose their deep chisel marks, and slight scratches,[1] or even smooth surfaces, to be substituted as the power of scouring became progressively feebler. Huge loads of rubbish could still be carried, and these would be dumped just below the rock-basin mouths. With still farther ice-retreat the loads would be dumped into the lower ends of the rock basins (lakes and sounds). Hence would arise great shallowing up at the sound entrances. With farther recession the glaciers would be unable to even *move* their former bottom loads, and then would ensue the overriding of moraines (formerly the tools with which the glacier accomplished its work). Still later stages would be marked by stagnant or inactive glaciers. Thus arise, in the author's opinion, the inactive glaciers of Alaskan, Norwegian, Alpine, and other canyon bases. They are enormous ice-masses, it is true, but the fact must not be lost sight of that they are but the veriest pigmies as compared with their colossal representatives during the Ice Flood. Still again, the channel grades existent at present were formed *during the flood*, and as such the channels of today at these localities are too wide, and possessed of slopes too much reduced, for corrasion to be noticeable in the present ice-drought stage.

[1] The declines of the troughs would be more scoured in these later stages than the lower inclined floors. Nevertheless, in the Ice Period these were more deeply chiseled.

Therefore we should expect readjustment of *grades* at present. So far is this distant in point of time that the deep rock basins are still only partially filled up. Until such readjustment of stream grades be brought about, *aggradation and stagnation* with local minor corrasion will be the only expression of present-day ice-action.

In comparing these "facts of form" in New Zealand with those of other strongly glaciated regions *in areas of steep profound canyons having short runs to baselevel*,[1] such as Alaska, Norway,[2] and Patagonia(?), we are struck with the wonderful similarity between the several topographies. In all are found the same tremendous fiord depths, the steep bordering walls, the peculiarly shaped rock basins, the truncation of spurs, the wealth of domes, the magnificence of the *cirques*, and the prevalence of "hanging" valleys. In all is observable the evidence of a former widespread intense glaciation. The steep-walled canyons possess their peculiar features in the most marked degree near the points of convergence. In no formerly non-glaciated region are such features obtainable; indeed, non-glaciated New Zealand and Australia stand out in the most marked contrast. It has also, in the previous pages, been shown that, on the assumption of an ice-flood—a fact which cannot be disputed—the observed forms are precisely those which could be expected. If New Zealand forms are explicable on the hypothesis of stream canyons modified by ice-floods, so also are those of Alaskan, Norwegian, Alpine, Sierran, and similar localities.

A couple of other points might be touched on at this stage, the remainder being reserved for treatment when considering the objections raised by several leading geologists to the theory of profound ice-modification.

1. Subsidence has often been advanced to explain the depth of fiord waters. Against this the writer[3] would strongly protest, unless supported by observation. It is utterly opposed to the evidence yielded by a study of *recent* New Zealand and eastern Australian

[1] I. e., great comparative velocity by steepness of ice-fall, convergence of canyons, etc.

[2] The Californian Sierras, the Rockies, and the European Alps doubtless fall also into line with these localities.

[3] For New Zealand.

topography. Subsidence postdating glacial times there has certainly been in New Zealand and Australia, but apparently to nothing approaching the depths required to sink these old ice-channel floors 2,000 feet or more below the sea-surface.

Furthermore, the fact of the striking depths found in the Norwegian, Alaskan, and Patagonian fiords, and the strong contrasts presented thus with associated non-intensely glaciated areas, are very suggestive.

Rock-basin excavation along old stream channels below base-level during periods of maximum ice-floods combined with *slight* later drowning is a sufficient explanation.

2. *Cirques* also appear explicable on the assumption of ice-sapping,[1] and find their counterparts in stream-action in rock basins excavated by the undermining action of water falls.

The magnificence of the glacial features (lakes, sound basins, cliff slopes, *cirques*, etc.), as compared with the holes, bank-cuttings, and flood-heaps formed by water, is due to the fact that in the case of the one the corrading agent was confined to a trifling portion only of the valley, while in the case of the other the glacier occupied the whole of its valley.

ANSWERS TO OBJECTIONS

In H. L. Fairchild's recent glacial note[2] a great number of hitherto unanswered objections to glaciation as an efficient corrader are advanced. To most of these the ice-flood hypothesis furnishes a satisfactory answer.

Thus (p. 19) Fairchild adduces the frequent presence of rock-polishing and slight ice scratches only instead of "deep groovings and cornice-like flutings" as evidence against the efficiency of ice-erosion.

Now, these smooth surfaces, slight scratches, and general absence

[1] See also Willard D. Johnson, "The Profile of Maturity in Alpine Glacial Erosion," *Journal of Geology*, Vol. XII, No. 7 (1904); also Dr. G. K. Gilbert, "Systematic Asymmetry of Crest Lines in the High Sierra of California," *ibid.* Since writing the above, Professor Albrecht Penck has sent the author a paper on "Glacial Features in the Surface of the Alps," *ibid.*, Vol. XIII, No. 1 (1905). In this remarkable paper the author sees additional confirmation of his "ice-flood" hypothesis.

[2] "Ice Erosion Theory a Fallacy," *Bulletin of the Geological Society of America*, Vol. XVI, pp. 13–74, Plates 12–23.

of deep groovings are exactly what we should expect to find on the hypothesis of a former glacial flood and present ice-drought. For the old channel was adjusted to its ice-flood load; the ice-recession was gradual, and work now, instead of being directed toward deepening flood basins, was confined to weaker dragging of loads and minor cutting. In these processes the deep flutings, etc., must to a great extent disappear.

(P. 20) With regard to flexibility of glaciers: Water cannot hold its load stiffly up to its work; yet the observations of the author along New England (New South Wales) stream tracks prove that water can hold bowlders up so effectively that marvelous demolition of spurs and channel bottoms is soon brought about.

With regard to many roche moutonnée forms, we should look upon them as tending to produce stagnation in a viscous mass away from the main drainage lines. We should also, as with water, expect to see far more work done on the downfall side of a rock mass than on its inclined side.

(P. 21 [4]) The analogy need not be carried beyond granting apparent viscosity and flow for glaciers. It does not here concern us what causes the motion. What we feel sure of is: Increased volume gives added velocity, and with flowing masses this gives wonderfully increased efficiency of transportation and corrasion.

Page 21 (5) does not carry weight, in the face of the fact that the present Muir glacier is indisputably a drought-glacier stagnating in its old *broad and more than baseleveled* valley.

(Pp. 22, 23 [7 and 8]) These objections are answered later.

(P. 26) Fairchild claims that rapid corrasion by ice is a self-checking process. If one watches a stream, he will see all the stages of bank-cutting, aggrading, and load-shifting in progress at the same time. Streams, either of ice or of water (or any viscous matter whatever), must adjust themselves to their burdens. If a flood is on, the stream will cut vigorously in one place and aggrade in another. With diminution in volume, transportation sets in until the excess of load is removed. Yet all the time the material is surely being carried to the grand baselevel. This is the way the glacial saw clears itself for cutting.

(P. 27) In areas removed from the centers of drainage lines ice

must override obstacles, even as the back waters of a high flood must. Corrasion is here reduced to a minimum, for the simple reason that these areas are not situated along graded channels.

The overriding of drumlins by ice-masses is what must be expected *at any stage* succeeding to the *high floods* which produced them. The drumlins are analogous to the great masses of débris piled up along the banks or along the channels of a stream during high flood. With the recession of the flood the load is dropped, and the babbling brooklets of subsequent dry phases must either trickle through or override the débris. But as for water, so for ice, the drumlins owe their existence to former floods.

(P. 27) "Could not a very deep glacier, having great pressure on its bed, along with a steep gradient, giving high velocity, rapidly abrade its bed?" Fairchild says "No!" But why not? It is only *along* these old preglacial lines, whether belonging to the newer canyon stage or to the older valleys of the flexed upland remnants converging into the canyons, that we claim such erosive power. We do not even need steep channel grades. A sharp convergence of two canyon glaciers into one very little larger in cross-section, especially if the walls are strong and deep, will furnish the velocity needed to give the increased efficiency of erosion needed.

But, as before remarked, over the bulk of the area—i. e., in inter-stream channel areas—we do not expect much cutting work to be done.

(P. 28) Fairchild states that basin excavation is less probable than valley-widening. We maintain that in New Zealand sounds the evident aim of the glaciers *is* to widen and flatten their floors. At certain points of convergence, however, especially when the high and strong walls are confined, the thrusts find partial expression during high floods in basin excavation the while undermining operations are going on. (See *ante*, also diagrams and photographs.) We are thoroughly acquainted in New Zealand with the tendency to widen valleys by ice.

(P. 31) These points have all been answered in other parts of the report on the ice-flood hypothesis. Similarly the peculiar basins of the Sierras, Cascades, Alaska, Norway, and New Zealand have been shown to result from ice-floods along channels of *profound* preglacial canyons, especially just below points of canyon convergence.

Of course, in an area of preglacial drainage carried to late maturity or early old age, especially in areas of gentle or moderate relief only, we would expect comparatively little action to be manifest even during the height of the ice-flood. This point should always be kept in mind by anyone comparing such widely varying regions as England, the Canadian plains, or Norway.

Where the stream-flood dashes its load angrily along the torrent tracks of a youthfully dissected plateau, there should we expect to see the vigorous thrusts of converging canyon glaciers. Now, Alaska, Norway, New Zealand, and Patagonia (?) are countries having young profound canyons intrenched in high plateaus. New England and many other places appear to have had their preglacial drainage well advanced. Apart, then, from certain minor features in their canyoned plateaus, we should expect to see evidence only of comparatively sluggish glaciers. This also applies to Fairchild's criticism on p. 33.

(Pp. 34, 35) Greenland has passed through its ice-flood phase as well as other regions, and therefore *its glaciers should now be stagnant as compared with their ice-flood representatives.* The *main* work was accomplished along the centers of the preglacial drainage lines, and the swarming of the ice-cap over areas of irregular hills and hollows is analogous to the "backing-up" action of ordinary flood waters against obstacles. During the height of the flood the grades of the old drainage were altered to meet the requirements of the heavy ice-cap. Now, of course, heavy as the ice-masses are, they are hopelessly incompetent to the task of corrading these old channels.

Even during the maximum ice onslaughts the ice in inter-stream areas could only corrade strongly if it discovered (or formed) a drainage line. Otherwise it would simply override hills and aggrade here and there.

(Pp. 37, 38) Referring to Professor A. C. Lawson's description of the Kern Valley, we venture to suggest that the previous notes explain these features.

(Pp. 39, 40) Without having seen Lake Chelan, we venture to suggest that it may be analogous to certain apparently non-strongly glaciated valley portions in New Zealand. Yet this is to be expected,

since some portions of a stream bed are preserved, while others are deeply corraded during flood stages. But in every instance in the New Zealand fiord region where lake basins, etc., occur, we could have predicted the same from the peculiar conformation of the associated canyon structures. Lake Chelan should be studied with this in view.

(P. 41) To the objections raised on this page it can only be again said that ice-action in infantile, youthful, mature, and other phases of plateau-dissection must not be confounded.

(P. 42) This present condition of the Muir and other glaciers is what *must* result on the assumption of a former efficient ice-flood. The glaciers are now in their drought stages, and lack all capacity for corrasion along their old *basined* channels.

(Pp. 42–46) Fairchild, in criticising Dr. Gilbert's report, apparently considers that physiographers claim the *general* deepening of fiords, etc., to the extent of thousands of feet. Now, in New Zealand, these rock basins, although immense, are yet only a portion of the canyon lengths, and mark the points of convergence of deep canyons. Along the upper canyons for many miles the floor may be flat or exist as a series of terraces.[1]

Thus Wakatipu arises from convergence of the Dart and Rees canyons; Milford Sound arises from convergence of the Arthur and Cleddau valleys; while these valleys themselves are fairly flat, and their bases are probably nearly 2,000 feet above the lake and sound floors.

With respect to the differential erosion *along the fiords* (i. e., preglacial drainage *channels*), and on Annette Island, it must always be remembered that, as a rule, *in the converging narrows the streams scour, while on the associated broads they aggrade.*

As for the view, held possibly by some, that the fiords are wholly the product of ice-scour, all the physiographic evidence in New Zealand points to the fact that the ice-action was confined to working fiercely along the central drainage lines, with production of *local* spurless chasms, rock basins (sounds and lakes), and double wall slopes, alternating with comparative stagnation of glaciers at points where one would expect stream-action to be expended in aggrading.

[1] See also Willard D. Johnson, "The Profile of Maturity in Alpine Glacial Erosion," *Journal of Geology*, Vol. XII, No. 7 (1904).

One would thus naturally expect to get islets remaining after the glacial flood occupation of a wide fiord, since this is the *stagnant* divergent, as opposed to the *rock-basining* convergent, canyon stage.

SUMMARY

The problem is a physiographic one, since it deals with the origin of present-day rock contours. It is analogous to the study of stream channel and bank contours.

Southwestern New Zealand was in pre-Tertiary time dissected by subaerial agencies to the early old-age stage.

In early Tertiary(?) time this so-developed surface was flexed, attaining a height of about 6,000 feet in the northern portions. Massive residuals of this plateau attained heights of 10,000 feet above sea-level.

During preglacial times the canyons of this area were determined by stream-action. The channels of these water-courses possessed harmonizing grades.

Their present contours are the result of marked modification by ice-action during the period of maximum glaciation.

The Great Ice Age marked a flood in ice-action, while the present much warmer conditions obtaining in formerly intensely glaciated regions are significant of a glacial drought.

The action of this ice-flood is best illustrated by comparing with the stages of an ordinary stream in flood.

In the case of ordinary streams, mighty floods along alluvial flats are frequently observed to *scoop out* holes many feet below these temporary baselevels, especially at points where marked stream convergence occurs. Along either the broads or the bank opposite to that where active cutting is in progress, *aggradation* also occurs during the very height of the flood. With the rising of the stream above its banks, masses of *stagnant back water* also are produced, whose principal function is aggradation as opposed to degradation.

Recession of the flood waters brings about aggradation at the points where maximum excavation was carried on during the flood. Especially does this occur at spots where scooping out *below baselevel* occurred.

Similarly for the ice-streams of the Glacial Period in New Zealand

along the lines of preglacial drainage. Just below the point where two profound canyons junction to form one deep valley, comparable only in width with each of its feeders, the ice-masses converged, and, by analogy with viscous fluids, would thereby have their velocity increased. Thus during the height of the ice-flood, they ripped off spur ends, straightened the canyon walls, finally undermining the sides and *scooping out deep rock basins thousands of feet below base-* (sea-) *level.*

During the height of the glacial phase (flood stage), aggradation would progress hand in hand with canyon lowering and widening. Thus, wherever "narrows" in the canyons opened out into "broads," glacial action—so strong just below the points of canyon convergence—would here receive a decided check. This would also be very noticeable even during the rock-basining stage in the narrows. Again, as in the case of ordinary streams, we should, on this theory of ice-action, expect practical ice-stagnation at the majority of points at distances from the centers of the main drainage lines. Thus ice-masses swarming over the canyon rims, and flooding the stream-dismantled plateau, would find their counterparts, in stream-action, in the "back-water" of a flooded river. It might be, of course, that, in the case of ice, some old, deserted plateau channel might be found along which corrasion could be effected; or it might be that the mass would start corrading some steep sea declivity and form "hanging" valleys, the return of warm conditions checking ice-corrasion at this stage.

After the ice-flood came recession of the glaciers. As with ordinary streams, *aggradation* and *smoothing* (along declivities) now became the work of the ice-drought glaciers.

Along the rock basins, undercut walls, etc., which marked the work accomplished by the ice-flood near and below baselevel, the rapidly diminishing glaciers would be mainly employed in obliterating the traces of their former handiwork.

1. They would partly or wholly efface and smooth over their original deep rock groovings, formed during vigorous ice-thrusts.

2. Smoothing of rocks would later practically cease and aggradation commence.

3. Ice-stagnation or overriding of gravels would finally ensue.

For a little reflection will show—as with ordinary streams—that at these points the valleys are too broad, and their grades have been too reduced, to permit of work other than aggradation.

As with streams, again, so with the retreating glaciers. On the least reduced slopes a little cutting will be still accomplished, but aggradation, moraine-overriding, and general ice-stagnation will now characterize these *old* channel grades which formerly expressed *the slopes in which the glaciers of mighty ice-floods only could effect corrasion.*

Hence, in my opinion, arise the present stagnant, although possibly large, glaciers of regions such as the Alaskan and Norwegian fiords; for along the *old flooded channels* of such localities, before they can again resume cutting, they must readjust their channel grades. Until such time they will be engaged removing excess of load, in filling up of rock basins. Even a slight ice-flood at the present stage would have its operations mostly confined to aggrading.

"Hanging" valleys mark the differential erosion of main and tributary channels during the *height* of the ice-flood. Undermining of canyon walls and truncating of spurs near convergence of narrow valleys would cause recession of tributary graded channels, and at these points one would naturally look for fine examples of "hanging" valleys. A magnificent example for study is afforded by Milford Sound along its northern wall. Here, just below the junction of the Arthur and Cleddau canyons, the "hanging" valleys, double wall slopes, and aligned walls are pronounced. A little lower down, the Harrison Cove canyon comes in, and immediately below this the deep rock basin, actually overhanging lower wall, and magnificent "hanging" valley occur. On the more protected southern side these resultant thrust forms are not nearly so pronounced.

Subsidence as an explanation of the great depths of the southwestern New Zealand sounds is utterly opposed to the evidence yielded by topographic studies in non-glaciated Australia and New Zealand. Rock-basin excavation *below baselevel* by thrusts from convergent ice-masses[1] is a sufficient explanation, and accounts also for the disposition and shapes of all the associated forms.

Cirques arise from ice-sapping action, as with ordinary waterfalls.[2]

[1] Of course, here, as in New Zealand and eastern Australia generally, a postglacial subsidence to the extent of several hundreds of feet must be admitted.

[2] See also A. Penck, and W. D. Johnson, *ante*.

The magnificent basins, lower cliff slopes, *cirques*, etc., due to ice-action as compared with basins, banks, etc., cut by water, are due to the fact that in the case of the latter the corrading agent occupied an insignificant portion only of the canyon, while in the case of the former the glacier occupied the whole of its valley.

Too great emphasis cannot be laid on the fact that these features are those which might be expected in areas of former high plateaus in which profound canyons had been excavated during *preglacial* times, and in which valleys marked convergence is a characteristic. Such areas as the Alaskan, Norwegian, Patagonian, and New Zealand fiord and canyon regions, the Rockies, the Sierras, the Alps, etc., appear to answer this description. *In these localities occur the forms predicted on the theory of modification by an ice-flood.*

But in areas belonging to the late-maturity or early old age of stream-erosion, also in areas of very unstable structures the resultant forms will be less strongly marked.

The influence of a continental ice-sheet during the ice-flood is not here discussed, the writer not having visited such a region. The resultant forms, however, could be predicted according to the degree of stream development attained in preglacial times, and to the length of time occupied in ice-cutting.

APPENDIX

AN APPEAL TO "GRADING" AS AN EXPLANATION OF THE PRESENT NEW ZEALAND FIORD, LAKE, AND CANYON CONTOURS

It may now be confidently asserted, as shown in the author's earlier reports, that the fiords, lakes, and canyons in New Zealand—as doubtless also those of Alaska, Norway, Patagonia, etc.—were due, in the main, to preglacial stream-action, and have since been profoundly modified by some mighty agent. The problem then reduces itself to: What is the origin of such striking dissimilarity of topographic contours in fiords and typical steam-developed canyons? The present note ascribes "fiord" topography to ice-streams in high flood (i. e., glacial period) flattening their grades, and excavating deep holes at points of marked canyon convergence.

All streams, of whatsoever material composed, seek to approximate to main baselevel as quickly as possible, but in so doing they are com-

pelled to establish channel grades along which to do *efficient* work. This follows immediately from gravitative considerations, and is illustrated by the grades of *all* stream channels as known to the author. The ultimate result of this continual approximation to baselevel is a complete flattening of channel grades. Flattening or lowering of channel grades is directly proportional to the strength of the eroding agent, and is a common fact of observation. A normal stream may possess a certain grade; a flood finds this so steep that it is enabled to reduce the grade locally, and *yet* maintain great efficiency as regards transportation. Thus at certain points, notably those of stream *convergence*, floods excavate holes below local or even *main* baselevel. These holes show *undercutting* of stream banks and reversal of channel grade down-stream. Stream studies show the amount of this excavation below baselevel to be directly *proportional* to the stage of stream development (i. e., steepness of grade) and the strength of flood. Thus a stream 5,000 feet deep working along a young channel would altogether overshadow the work accomplished by a stream 50 feet deep flowing along an excessively broad (i. e., a very flattened grade) valley.

Now, the glacial period was an *ice-flood*, the streams of ice, in the canyons (young channels) of southwestern New Zealand being more than 5,000 feet thick.

The action was evidently that of a viscous stream, there being a continuous slope in the mass from summit to baselevel. Therefore, from gravitative considerations, the ice-floods would find the channel grades of the insignificant preglacial streams so steep that they could induce in them excessive local flattening and *yet* maintain great efficiency of transportation; i. e., their general velocity, as shown by their still steep surface curves above baselevel, would still be considerable. The disparity in volume between ice- and stream-floods, even allowing for loss in velocity of ice, would induce, at certain marked canyon convergences, such flattening of grade as would (by analogy with stream studies in New England, New South Wales) be commensurate even with the *depth of the ice-stream.* Thus would here arise basins thousands of feet deep, showing reversed grades lower down stream; also the undercutting of canyon sides, and alignment of cliff bases.

Upon the retreat of the ice-flood or floods, one would expect—as with ordinary streams—to find the flood grade altogether *too flat* for

either efficient corrasion or transportation. The diminished glaciers would now be compelled to cease corrading at these points of flood scour and aggrade here until a working grade could be set up or another flood return to carry on its work.

Glaciers of the present ice drought should, therefore, lie inactive or stagnant along these flood-holes (i. e., fiord, canyon and lake basins), while overriding of moraines without transportation and aggrading of flood-holes would set in.

Such were among the theoretical conclusions[1] of the author after a preliminary tramp through New Zealand and a comparison with eastern Australian stream channels. This idea suggested the possible existence of "facts of form" unnoticed during the first short excursion to the Sounds, but nevertheless absolutely necessary to the success of the theory.

Opportunity was found later to examine Milford Sound while the idea was framing itself, and the forms sought were found. Thus in the *strong* crystalline schists of the famous fiord, the canyon walls, just below the convergence of the magnificent Cleddau and Arthur valleys, 5,000 feet deep, show steep upper slopes with marked *undercutting* up to great heights above the fiord base, an alignment of walls, absence of spurs, and an enormously deep rock basin. Just here a third and fourth canyon enter the narrow main channel, and the undercutting, with production of hanging valleys cut off by a great *rectilinear* wall, is very pronounced. Nothing could be more suggestive of rock basins excavated by ice-floods at canyon convergences than the old steep lateral channel grades of these "hanging valleys" now separated by vertical cliffs, due to undercutting, from the flattened grade of the main channel. Still lower down no side canyons come in, and the fiord soon shows a decided *reversal* of channel grade.

All this points to the work of a *flood* or of floods during the *youth of glacial attack.* This idea of youthful ice-attack, exemplified by fiord and canyon contours in strongly glaciated regions was first advocated by Professor W. M. Davis.

Subsidence thus appears to be *practically* negligible in forming present fiord depths.

[1] Other deductions made were the necessity for absence of this tremendous excavation at marked canyon *divergences;* and other points noted in main report. All these appeared to be satisfactorily seen at Lake Wakatipu, Preservation Inlet, etc. Dr. G. K. Gilbert's observation of lack of glacial erosion in Annette Island, Alaska, appears to be a case in point.